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PURDUE UNIVERSITY

SCHOOL OF
ELECTRICAL AND
COMPUTER ENGINEERING

September 1, 1999

Karen Buck
Air Force Office of Scientific Research
801 N. Randolph
Room 732
Arlington, VA 22203-1977

Dear Ms. Buck:

Please find enclosed my final report for contract F49620-98-1-0405.

Thank you.

Sincerely,

Andrew M. Weiner

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Enclosure

cc: ONR

Final Report

Air Force Office of Scientific Research
F49620-98-1-0405

Instrumentation for Research on Ultrafast Optical Pulse Processing and Applications

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Andrew M. Weiner

Andrew M. Weiner
Principal Investigator

Final Report

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I. Acquired equipment

We acquired the following equipment using funds from this contract:

Item	Quantity	Vendor	Description	Cost
1	1	Hewlett Packard	Optical Spectrum Analyzer	8,330.00
2	1	Technical Manufacturing Corporation	Optical table	9,634.50
3	1	Instruments SA	Monochrometer	14,510.00
4	1	ILX Lightwave	Laser diode control & mount	2,506.00
5	1	New Focus	Chopper	1,784.57
6	1	Optics for Research	Fiber polarizer	2,368.00
7	1	Electrophysics	IR Viewer	1,356.00
8	1	Crystal Systems	Ti:S rod	2,094.03
9	1	Oxford	Cryostat	17,613.00
10	6	Newport	Translation stages, 1 motorized, 5 X-Y-Z	8,631.45
11	1	Compaq	Computer	2,800.00
12	1	Innovative OE Comp GmbH	GHz detector	7,700.00
13	1	Cambridge Research	modulator arrays	14,721.50
14	1	SDL Optics, Inc.	Pump diode	4,885.00
15	1	Photon	Beam profiler	6,618.00
16	1	Melwood Laboratories	Detector w/ bias-T - free space, 40GHz	1,425.00
17	1	National Instruments	A/D system	2,085.00
18	1	Micron	A/D computer	1,637.87
19	1	Hamamatsu	Avalanche Photodiode	2,044.46
20	1	Corex Systems	Nonlinear crystal	1,790.00
21	1	Casix	Nonlinear crystal	1,290.00
22	1	New Focus	Balanced receiver power supply	2,351.17
23	1	Newport	Stages (Ti:S construction)	2,937.00
24	1	Integrated Optical	Phase Modulator	6,178.00
25	1	Burleigh	Fabry Perot Spectrum Analyzer	18,495.00
26	1	Lees Optical	Ti:S Mounts	1,602.95
27	1	CVI	Ti:S optics	229.22
28	1	Newport	Ti:S optics	935.00

Total cost: $146,771.50

There are some differences between the list of equipment purchased and the equipment list in the proposal. The most significant differences are as follows:

a) A solid-state laser (vendor: Spectra Physics) and a scientific CCD camera (vendor: Princeton Instruments), budgeted in the original proposal at $92,500 and $24,500, respectively, were acquired using other funds. Therefore, funds from this contract were available for the purchase of other needed pieces of equipment.

b) A high power diode laser, budgeted in the original proposal at $12,950 from SDL, Inc., was no longer available. Instead a lower power diode laser was purchased for $4885 from the same vendor.

These savings were applied to purchase other needed equipment. The most significant of these are as follows:

c) We purchased an optical table, titanium: sapphire crystal, optical stages, and laser optics (items 2,8,23,26,27, and 28) to be used in setting up a new femtosecond laser system.

d) We purchased a cryostat (item 9) needed for experiments on coherent control in semiconductor materials.

e) We purchased a beam profiler (item 15) for use in experiments on ultrafast pulse processing, ultrafast fiber communications for optoelectronic computer networking, and nonlinear optical generation of short wavelength light.

f) We purchased nonlinear optical crystals (items 20 and 21) for our research on nonlinear optical generation of short wavelength light.

g) We purchased a fiber-optic polarizer, several photodetectors, an integrated optical phase modulator, and a liquid-crystal spatial light modulator (items 6,12,13,16,19,22, and 24) and upgraded our optical spectrum analyzer (item 1) for our research on ultrafast fiber communications for optoelectronic computer networking and ultrafast pulse processing.

h) We purchased a Fabry-Perot spectrum analyzer (item 25) for research on ultrafast pulse processing and on optical imaging in scattering materials.

II. Research projects summary

Equipment purchased under this contract has been used by approximately fourteen researchers (one post-doc, ten graduate students, three undergraduates) for several research activities, summarized briefly below.

II.A. Ultrahigh-speed optical processing

A key goal of our research is to demonstrate all-optical methods for generation and processing of ultrafast lightwave signals. One example of one of the long-term applications of this work is to construct optical encryption boxes suitable for handling ultrahigh-speed optical data at rates beyond the capabilities of electronic processing. Two examples of our work using equipment from this contract is as follows:

- We have constructed and demonstrated a femtosecond pulse shaping apparatus where the generated waveform is a directly scaled version of a spatial masking pattern. This is in contrast to the usual pulse shaping geometry where the output waveform is determined by the Fourier transform of the spatial masking pattern. Our current configuration is preferred for applications involving generation of reprogrammable pulse packets for use in TDM optical communications, because each pulse can be associated with an individual element on a high-speed optoelectronic modulator array. Furthermore, we have analyzed and then experimentally tested the dispersion properties of this "direct space-to-time" pulse shaper for the first time, which is important for subsequent transmission of the output pulses over optical fibers.

- We have performed static and high-speed tests of a GaAs-MQW/Si-CMOS smart pixel arrays, which will soon be employed in the new pulse shaper noted above.

II.B. Ultrafast fiber communications for optoelectronic computer networking

One of our key research thrusts aims at experimental tests of an ultrashort pulse code-division, multiple-access (CDMA) optical communications system and of the devices needed to implement such a system. We have obtained several key results during the period of this contracted, listed below:

- Completely distortion-free propagation of 400 fs pulses over a 10 km fiber link by using dispersion compensating fiber for coarse dispersion control and a femtosecond pulse shaper for fine control of the residual cubic phase.

- Demonstration of byte-wide WDM transmission with very small (~1 psec) timing skew over 2.5 km of fiber, using dispersion compensation techniques similar to those above. These results are important for WDM-parallel transmission schemes for word by word transmission for optoelectronic computer networking.

- First ever demonstration of end-to-end ultrashort pulse CDMA transmission, including encoding and decoding using fiber pigtailed pulse shapers, complete dispersion compensation over a 2.5 km fiber link, and high contrast nonlinear optical thresholding to discriminate correctly decoded data pulses from incorrectly decoded pulses (interference).

In addition, we collaborated on experiments testing the digital transmission capabilities of new, extremely high speed light emitting diodes (LEDs) provided by colleagues at Purdue. Data rates up to 1.7 Gb/s were achieved with bit error rates below 10^{-9}, which is to our knowledge the fastest rates ever reported for LED transmitters. These results are important

for short length optical interconnects, e.g.,, for backplanes interconnecting electronic processors.

II.C. Femtosecond optical manipulation of terahertz (THz) radiation

We have investigated the use of shaped optical pulses to manipulate THz radiation emitted by biased photoconductor samples as well as via optical rectification from second order nonlinear optical materials. Previously we demonstrated several interesting forms of THz waveform control from photoconductive samples, e.g., tunable narrowband THz radiation in the 750 GHz-1.2 THz frequency range. We have also shown that the use of femtosecond pulse trains allows a considerable enhancement of the peak THz power spectral density through avoidance of saturation effects. We have now compared THz waveforms measured by using photoconductive dipole antennas and by using electro-optic sampling. These measurements elucidate the role of the frequency-dependent antenna response in waveform measurements using photoconductive receivers. In collaboration with Los Alamos National Laboratory, we have also investigated the THz radiation response of large aperture photoconductors excited by pulse sequences derived from the output of a high power femtosecond amplifier system. Our results demonstrate a nearly one order of magnitude enhancement in the peak THz power spectrum at the frequency corresponding to the pulse sequence repetition rate and clarify the role of the material properties in the saturation physics governing photoconductive THz transmitters.

II.D. Laser speckle for characterization of and imaging within optically scattering media

We are investigating a new technique for characterization of and imaging within dense optically scattering media based on observation of laser speckle statistics at the output of the medium. The key concept is that the modulation depth of the laser speckle depends on the variance in the photon travel times through the medium relative to the laser coherence time. Therefore, the speckle statistics are sensitive to inhomogeneities within the scattering medium. During the period of this contract, we have performed experiments demonstrating the use of a narrow-linewidth but tunable laser diode to synthesize light with a variable and controllable optical bandwidth (and hence a controllable coherence time). This technique for coherence time synthesis enhances the practicality of our speckle imaging approach by allowing optimization of the laser coherence time for best imaging contrast. Using this approach, we have performed the first experiments demonstrating this laser speckle approach for visualizing and imaging inhomgeneities within highly scattering optical media.

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11. SUPPLEMENTARY NOTES

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13. ABSTRACT *(Maximum 200 words)*

Our first request is for a high power diode-pumped and frequency-doubled solid-state pump laser, which will be used to upgrade an existing femtosecond laser system used in this research. Compared to our current argon-ion pump laser, the new solid-state pump laser will dramatically improve the stability, noise performance, and operating costs of our system, which we anticipate will significantly impact our reseach results. We also request a high-power diode laser which be used to pump home-built fiber-based ultrafast laser systems required for ultrafast pulse processing and optoelectronic computer networking experiments. Finally, we request funds for a spectrometer and CCD system which will provide both spatial and spectral diagnostics required for our research on space-time optical processing and on nonlinear optical generation of short wavelength light.

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